The Egyptian Journal of Radiology and Nuclear Medicine (2015) 46, 79–87

Egyptian Society of Radiology and Nuclear Medicine

The Egyptian Journal of Radiology and Nuclear Medicine

www.elsevier.com/locate/ejrnm
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ORIGINAL ARTICLE

Diagnostic accuracy of three-dimensional contrast-enhanced automatic moving-table MR angiography in patients with peripheral arterial occlusive disease in comparison with digital subtraction angiography

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Received 9 August 2014; accepted 13 November 2014
Available online 6 December 2014

KEYWORDS

MRA;
Automatic moving table;
Angiography;
Peripheral arterial occlusive disease

Abstract *Objective:* The aim of this study was to compare the diagnostic accuracy of contrast-enhanced (CE) three-dimensional (3D) moving-table magnetic resonance (MR) angiography with that of selective digital subtraction angiography (DSA) for routine clinical investigation in patients with peripheral arterial occlusive disease.

Methods: Between April 2012 and May 2013, the lower extremities of 30 patients with suspected peripheral vascular disease performed both conventional digital subtraction angiography and three-dimensional contrast-enhanced MR angiography MRA with the automatic table movement technique (MoBI-trak). DSA and MR angiographic images were interpreted prospectively, one vascular radiologist interpreted the digital subtraction angiographic images and the second vascular radiologist interpreted the MR angiographic images; both interpreters were unaware of the clinical history and the results of the other examination.

Results: The MRA and DSA studies in the 30 study patients produced 870 arterial segments for interpretation. The sensitivity of MRA for the detection of mild stenotic, hemodynamically severe stenotic and occlusions were 86.1%, 90.5% and 93.9%, respectively. Corresponding specificity was 90.1%, 96.1% and 97.5%, respectively.

Conclusion: Our prospective comparison shows that three-dimensional contrast-enhanced automatic moving-table MRA is a noninvasive imaging modality that has a diagnostic accuracy comparable to DSA for the assessment of peripheral arterial occlusive disease.

1. Introduction

Peripheral arterial occlusive disease (PAOD), which is primarily caused by atherosclerosis, has an incidence of 4.5–8.8% in

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Peer review under responsibility of Egyptian Society of Radiology and Nuclear Medicine.

http://dx.doi.org/10.1016/j.ejrnm.2014.11.007

men older than 55 years. While the diagnosis is based on clinical examination and the results of ankle-brachial index measurements, accurate depiction of pelvic, femoral, and runoff vessels is desirable in order to formulate a therapeutic approach (1).

Peripheral angiography is one of the most common angiography applications of today. Whereas X-ray was the only modality to visualize a large tract of vessels from the abdomen down to the feet, with the introduction of Doppler ultrasound techniques and the development of duplex scanners it has become possible to diagnose many lower extremity arterial abnormalities without having to subject the patient to the most invasive arteriography (2).

Magnetic resonance subtraction for the evaluation of lower extremity arteries was first reported in 1986, by Meuli et al., where projective imaging of the arteries of the lower extremities was obtained (3).

Neither Doppler ultrasound nor magnetic resonance angiography (MRA) was sufficiently accurate to fully replace angiography. MRA was preferable to us as a non invasive test when vascular intervention was contemplated.

Although phase contrast MRA was superior to time of light (TOF) MRA, the most accurate results were achieved when the two methods were combined (4).

Magnetic resonance angiography is increasingly used as a noninvasive alternative to digital subtraction angiography. Besides plain time of flight and phase contrast MRA a new MRA technique using positive contrast agent has been introduced recently. A fast 3 D gradient-echo sequence is applied to reach a significant reduction of measurement time for acquisition of the MRA within the first pass of the contrast agent, thereby avoiding venous overlap. A significant progress was yielded by MR systems allowing table movement for examination of the pelvis and the lower limbs in one examination with a single contrast agent bolus (5).

The automatic floating table system allows comfortable noninvasive examination of pelvic and lower limb arteries. The value of this technique in comparison to DSA has to be determined in future studies (5).

2. Patients and methods

Between April 2012 and May 2013, the lower extremities of 30 patients with suspected peripheral arterial occlusive disease that presented to the surgical outclinic, with intermittent claudication ($n = 19$) and rest pain ($n = 11$) were studied.

All patients were subjected to three dimensional contrast enhanced MRA with the automatic table movement technique (MoBI-trak) and digital subtraction angiography for the aorta and lower limbs with a maximum interval period of 2 days.

2.1. Contrast enhanced MRA

All examinations were performed with a 1.5 T MR system (Gyroscan Philips, Eindhoven, Holland). Body coil was used for signal transmission and reception. All examinations were done by the same examiner. No special patient preparation was requested.

The moving bed infusion tracking MR angiographic sequence was a three dimensional gradient-recalled-echo (Fast field echo) technique. Field of view 500 mm and a matrix size 512×171, which resulted in a voxel volume of 8.4 mm^3. This sequence was implemented in a dynamic fashion to acquire three identical coronal volumes; the dynamic study was acquired twice, once before infusion of contrast material and once during infusion.

Before collecting the three-dimensional data sets, the scan delay for the first three-dimensional acquisition after beginning the administration of contrast material into the antecubital vein was determined. For this requirement, 2 mL of Magnevist paramagnetic contrast material (Schering, Berlin, Germany) was injected with a flow rate of 0.5 mL/s with a power injector and was followed by a saline flush of 20 mL. To determine the bolus transit time from the place of injection to the vessel under consideration, an axial two-dimensional, fast field echo sequence was performed above the aortic bifurcation. There were 50 dynamic scans acquired in 1:15 min (1.5 s/image).

For imaging the peripheral vessel tree in patients in this study, three stacks were acquired with the moving-table software MoBI-trak, allowing fast movement of the patient table during contrast material injection. These sequences, consisting of three stacks (aortoiliac, femoropopliteal, calf), were repeated twice: once before contrast material injection, starting at the calf vessel, and then the second scan starting at the pelvis during administration of 40 mL of paramagnetic contrast material (0.2–0.3 mmol/kg body weight). The contrast medium was injected in every patient with a power injector with a flow rate of 0.5 mL/s, followed by a saline flush of 20 mL (flow rate, 0.5 mL/s).

By using prototypic post processing tool complex automatic subtraction was performed, and orthogonal maximal intensity projections of all three stacks were reconstructed immediately, allowing continuous delineation of the arterial vessel tree from the aortic bifurcation up to the ankle. Post-processing time between the end of image acquisition and presentation of three orthogonal subtracted maximal intensity projections of every stack took as long as 10 min.

2.2. Digital subtraction angiography

All conventional angiography examinations were performed by using a digital subtraction technique. DSA images were acquired by using a 38-cm field of view and an image matrix of 1024×1024 pixels.

Sixteen to twenty milliliters of the contrast agent was injected into each station at a rate of 8–10 ml/s by using a power injector and sequential DSA images were obtained. The patient was then repositioned for imaging of a new area of anatomy. In all patients, arteriography was performed in the frontal plane and in some patients, lateral view for the leg was obtained.

3. Image analysis

DSA and MR angiographic images were interpreted prospectively, one vascular radiologist interpreted the digital subtraction angiographic images and a second vascular radiologist interpreted the MR angiographic images.

Three-dimensional MR angiographic data sets were available on a workstation permitting review of the source images as well as interactive reformation at the time of interpretation. DSA was used as the standard of reference.

The arterial system was divided into 29 segments for analysis: 1, distal infrarenal aorta; 2, common iliac artery; 3, internal iliac artery; 4, external iliac artery; 5, common femoral artery; 6 and 7, superficial femoral artery divided into proximal and distal halves; 8, popliteal artery; 9, tibioperoneal trunk; 10 and 11, anterior tibial artery divided into proximal and distal segments; 12 and 13, peroneal artery, divided into proximal and distal segments; and 14 and 15, posterior tibial artery divided into proximal and distal segments.

A stenosis of 50% or more was considered hemodynamically significant.

Each segment was assessed on the following scale

0 = normal
1 = grade 1 stenosis, minimal wall irregularity (1–19% stenosis)
2 = grade 2 stenosis, less than 50% (20–49%)
3 = grade 3 stenosis, (50–99%)
4 = grade 4 occlusion (100% stenosis)

Sensitivities and specificities were calculated for all segments together and for each vessel segment separately.

4. Results

DSA depicted 870 segments in 30 patients with an abnormality present in 440 segments. Grade 1 stenosis was detected in 200 segments. Grade 2 stenosis was present in 77 segments, and grade 3 stenosis was demonstrated in 72 segments. 91 segments were occluded.

MRA agreed with DSA in 819 segments and disagreed in 51 segments. The accuracy of MRA was 94.1%.

Sensitivity and specificity of MRA in grade 1 stenosis were 75.6% and 82.1%, respectively.

Sensitivity and specificity of MRA in grade 2 stenosis were 86.1% and 90.1% respectively.

Sensitivity and specificity of MRA in grade 3 stenosis were 90.5% and 96.1%, respectively.

Sensitivity and specificity of MRA in grade 4 stenosis (occlusion) was 97.5% and 82.1% respectively.

The MR angiographic images overestimated 30 vascular segments (3.4%) as grade 3 (severe stenosis). On DSA images 20 segments appeared as grade 4 stenosis and 6 segments as grade 1 stenosis.

The MR angiographic images underestimated 21 (2.4%) vascular segments as grade 2 stenosis ($n = 7$) and grade 3 stenosis ($n = 14$). On DSA images they appeared to be grade 4 stenosis (see in Tables 1 and 2).

The MR angiographic images interpreted 4 segments as occluded which appeared as grade 3 stenosis on DSA images, whereas DSA images identified 8 segments as occluded which appeared as grade 2 stenosis ($n = 3$) and grade 3 stenosis ($n = 5$) on MR angiography (see in Figs. 1–3).

5. Discussion

Lower extremity arterial occlusive disease is an important cause of morbidity in developing countries and it results in an estimated 100.000 amputations or surgical bypass procedures annually in the united states alone (6).

Before peripheral vascular surgery, it is necessary to evaluate accurately the whole arterial system of the extremity in question, to Judge the run off, and to plan the localization of the peripheral anastomosis (7).

Conventional angiography is a widely used imaging modality that yields a ‘‘road map’’ of the vascular system, which is useful in choosing the optimal type and technique of revascularization procedure (8).

However, angiography provides mainly anatomical information but limited information about the physiological features of flow and plaque, has many limitations’, not free of risk and even may be associated with serious complications (9).

The most frequently reported complications include hematoma, bleeding, pseudo aneurysm formation, embolization, allergic reaction and renal failure (10).

Magnetic resonance (MR) angiography is emerging as a reasonable adjunct or alternative to the conventional approach of catheter angiography (11). The lower degree of invasiveness and smaller likelihood of complications with MR angiography are well received by patients and thus contribute to arguments promoting the cost-effectiveness of this examination (12).

However, the widespread acceptance of MR angiography has been hindered due to the artifactual signal intensity loss

Table 1 Comparison of degree of stenosis with digital subtraction angiography (870 vessel segments) and three-dimensional MR angiography (819 vessel segments).

Vessel segment	Grade of stenosis									
	Digital subtraction angiography					MR angiography				
	0	1	2	3	4	0	1	2	3	4
Aorta	9	16	1	0	2	6	14	2	0	2
Common iliac artery	29	22	7	5	2	23	20	8	6	2
External iliac artery	37	12	4	6	2	35	8	4	6	2
Internal iliac artery	31	10	13	9	1	21	9	11	11	3
Common femoral artery	37	12	12	3	1	33	10	13	5	1
Superficial femoral artery	41	24	10	22	21	36	21	12	25	20
Popliteal artery	28	16	4	2	5	25	13	6	4	5
Tibioperoneal trunk	38	12	5	4	6	37	9	7	7	6
Anterior tibial artery	56	30	6	6	20	55	25	6	8	15
Peroneal artery	69	25	5	8	9	67	21	7	9	6
Posterior tibial artery	55	21	10	7	23	49	17	11	10	25
Total	430	200	77	72	91	387	167	87	91	87

Table 2 Sensitivities and specificities of MR angiography for detection of stenosis in 819 vascular segments.

Vessel segment	Grade 1 stenosis		Grade 2 stenosis		Grade 3 stenosis		Grade 4 stenosis	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Aorta	88.2	83.2	70.4	96.6	–	–	100	100
Common iliac artery	80.4	91.2	89.1	92.8	91.3	97.8	100	100
External iliac artery	75.5	88.5	88.4	93.6	100	100	100	100
Internal iliac artery	90.4	89.8	80	80.3	93.9	91.7	70.4	96.2
Common femoral artery	78.5	86.3	79.8	94.9	85	90.3	100	100
Superficial femoral artery	88.9	84.1	91.4	87.4	95.3	97.1	97.3	98.7
Popliteal	73	82.5	90.5	94.8	93.7	98.7	100	100
Tibioperoneal trunk	90.2	79.4	95.7	93.2	86.9	97.7	100	100
Anterior tibial artery	85.6	74.8	85.9	90.3	89.8	95.7	79	80.2
Peroneal artery	83.2	73.1	88.6	75.3	80.3	98.2	90.3	98.5
Posterior tibial artery	86.2	70.2	87.4	92.1	89.5	96.4	96.4	98.9
Overall	75.6	82.1	86.1	90.1	90.5	96.1	93.9	97.5

and the lengthy examination time associated with time-of-flight MR image acquisitions (13).

Contrast-enhanced MRA has rapidly emerged as an attractive alternative to conventional angiography. The reason for this rapid acceptance in the ''vascular community'' is the close resemblance of images obtained with contrast-enhanced MRA to those obtained with conventional angiography (14).

Unlike phase-contrast (PC) MRA and time-of-flight (TOF) MRA, which are older MRA techniques, contrast-enhanced MRA does not suffer from artifacts caused by turbulence and in-plane saturation. For this reason, contrast-enhanced MR angiograms are easier to interpret than PC or TOF MR angiograms. Also, the lack of in-plane saturation makes it possible to image in the coronal plane, so that much larger anatomic regions can be covered. In general, the most important advantage of contrast-enhanced MRA in comparison with conventional MRA is the enormous reduction in examination time (15).

One drawback of gadolinium-enhanced 3D MR angiography is the limited field of view (40–50 cm) available on most MR systems (16).

However, some studies, such as an examination of the pelvic and lower extremity arteries, require that a larger area be evaluated. To image larger anatomic areas an alternative imaging strategy must be used.

Previously, when we needed to image large areas we obtained multiple gadolinium-enhanced 3D MR angiograms during a single examination (17).

So the imaging of the entire vessel tree requires both repeated placement of the patient, and multiple administrations of contrast media. The result is higher costs, long examination time, and reduced contrast-to-noise ratio in the stacks that are acquired second and third because of the increased contrast enhancement of the surrounding tissue. In addition, the repeated positioning of the patient could lead to missing some vessel segments between stacks (18).

Recently bolus chase 3D contrast enhanced MRA technique using a stepping table has been introduced to image several anatomical regions with a single contrast injection. This bolus chase MRA technique allows arterial mapping of the entire lower extremity within a short scan time using a single contrast injection, and it is increasingly used in clinical practice (19).

In the present study we used the most recent technique of contrast enhanced MRA, ''bolus chase 3D contrast enhanced MRA using automatic moving table''.

This technique combined the advantage of gadolinium enhanced 3D acquisition technique with table movement, as used in conventional angiography to allow imaging from the aorta to the ankles in a very short time.

The examination was tolerated well by all patients. There were no substantial adverse events following the injection of the gadolinium based contrast agent.

Perriss et al. (20) stated that CE-MRA is a useful adjunct to clinical and physiological examination for the evaluation of lower limb arteries in patients with end-stage renal failure.

The differentiation of diseased and patent vessels was possible in nearly all vascular segments. Furthermore, hemodynamically significant lesions were detected with excellent concordance with digital subtraction angiography.

Patients who would not be good candidates for MR angiography include, uncooperative patients, medically unstable patients, and those with claustrophobia, a pacemaker or intracranial aneurysm clips.

Our results were comparable with Janka et al. (21) (using the moving-table technique and dedicated peripheral angiography coil), they reported sensitivity ranging from 91% to 94%, specificity between 90% and 91% in detecting clinically significant stenoses and occlusion.

Our sensitivity was lower than Steffens et al. (22). They reported an overall sensitivity (for detection of stenosis $>50\%$) of 99.5%, and they reported higher specificity (98.9%) than ours. They concluded that bolus-chasing CE-MRA is a simple robust and easy to perform technique which provides high quality angiograms of the lower extremity arterial system and is comparable to DSA for the diagnosis of PAD.

Our results were slightly lower than Loewe et al. (18), using the bolus chase technique, who reported an overall sensitivity and specificity of 95% and 97%, respectively for the detection of clinically significant stenosis.

Hentsch et al. (23) compared the moving-table 3D CE-MRA with intra-arterial DSA, for the detection of clinically significant stenoses 93% sensitivity and 90% specificity were achieved in on-site evaluation, with 71–76% and 87–93% off-site; for the detection of occlusion, sensitivity and

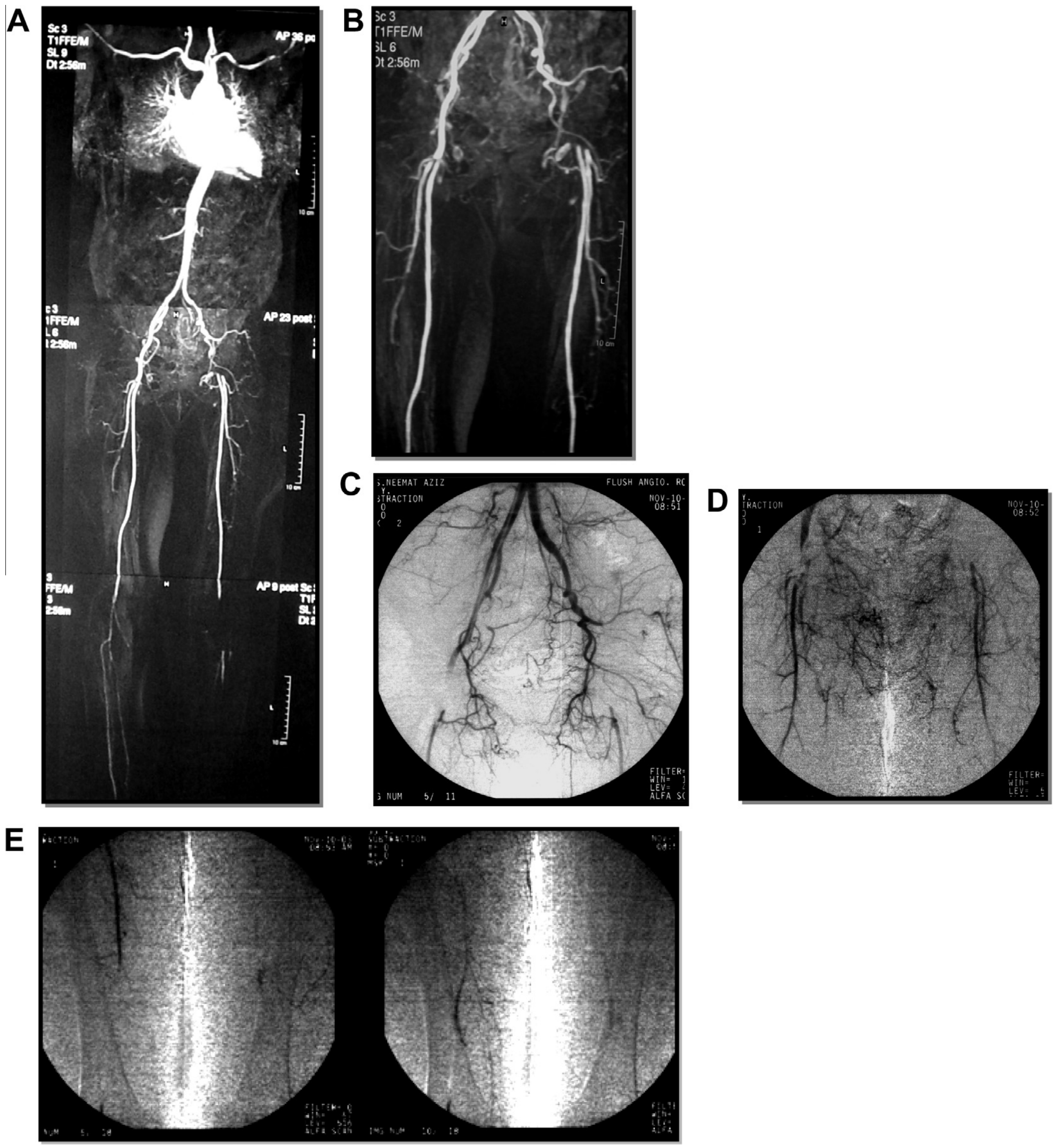

Fig. 1 (A) Summated MIP 3D CE-MRA image showing the arterial tree form the major branches of the aortic arch as well as the arterial tree of both lower limbs. Attenuated distal right popliteal artery and occluded distal part of the left popliteal artery. (B) 3D MIP CE-MRA showed occluded left EIA and left CFA and focal ostial compromise of the right femoral bifurcation. (C) DSA showed occluded left EIA and left CFA as well as failure to opacify the right CFA. (D) DSA showed occluded left EIA and left CFA as well as failure to opacify the right CFA. (E) DSA showed occluded distal part of the right SFA with attenuated distal left SFA.

specificity on-site were 91% and 97%, with 75–82% and 94–98% off-site. They concluded that CE-MRA gave results comparable to those of DSA for larger arteries of pelvis and thigh, results for calf arteries were compromised by spatial resolution and technical limitations.

Our results were higher than Ho et al. (24), who reported sensitivity of 93% for the detection of clinically significant stenoses.

Our results also were much higher than Meaney et al. (25), who reported sensitivity of 81%, and specificity of 91%for the detection of clinically significant disease.

In this study both MRA and DSA were agreed in 819/870 segment (conformity 94.1%) and disagreed in 51 / 870 segment (5.9%). These findings were slightly higher than those of Loewe et al. (18) who reported overall conformity in precise stenosis classification of 90%.

Our results showed that severe stenoses were correctly identified on MR angiography with an overall sensitivity and specificity of 90.5% and 96.1%, respectively. Overestimation of stenoses occurred more frequently ($n = 30$) than underestimation ($n = 21$). Correlation between MR angiography and DSA was lower in cases of mild disease, but even in these cases sensitivity and specificity values ranged between 70% and 90%.

Ho et al. (26) stated that the overestimation of degree of stenosis by MRA might be due to the rectangular shape of the voxel used with the moving-bed infusion-tracking MR angiographic sequence, given the possible partial volume effects in the anteroposterior (section-thickness) and

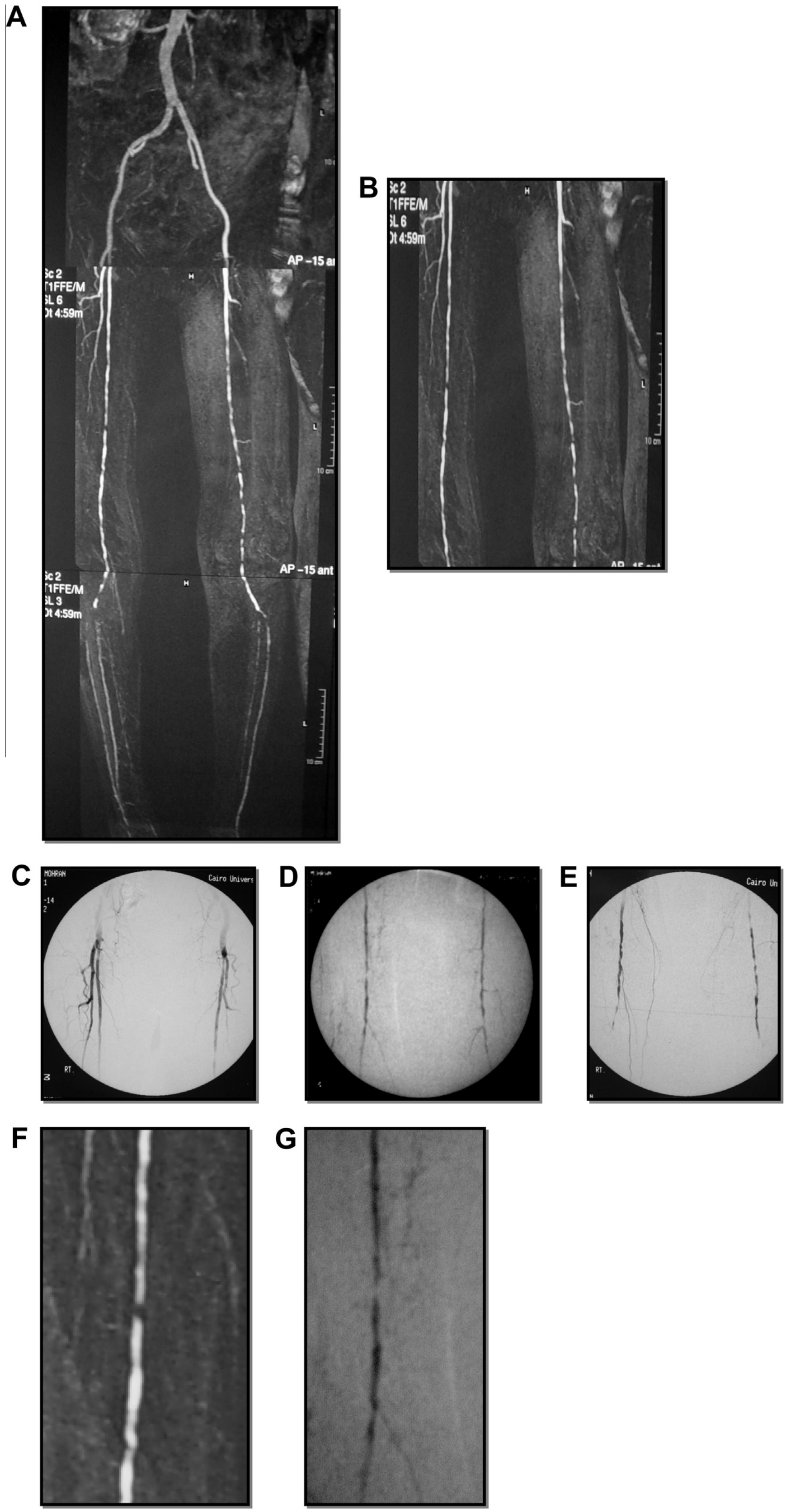

Fig. 2 (A) Summated coronal 3D CE-MRA image of the entire abdomino-pelvic and lower limb arterial tree. (B) 3D MIP CE-MRA showing beaded appearance of the SFA due to multiple significant stenotic lesions. (C–E) DSA of the femoro-popliteal segments showing beaded appearance of the distal 2/3 of both SFA and popliteal arteries. (F) MRA and (G) DSA at the level of the right SFA showed that MRA overestimated tight stenosis into focal occlusion.

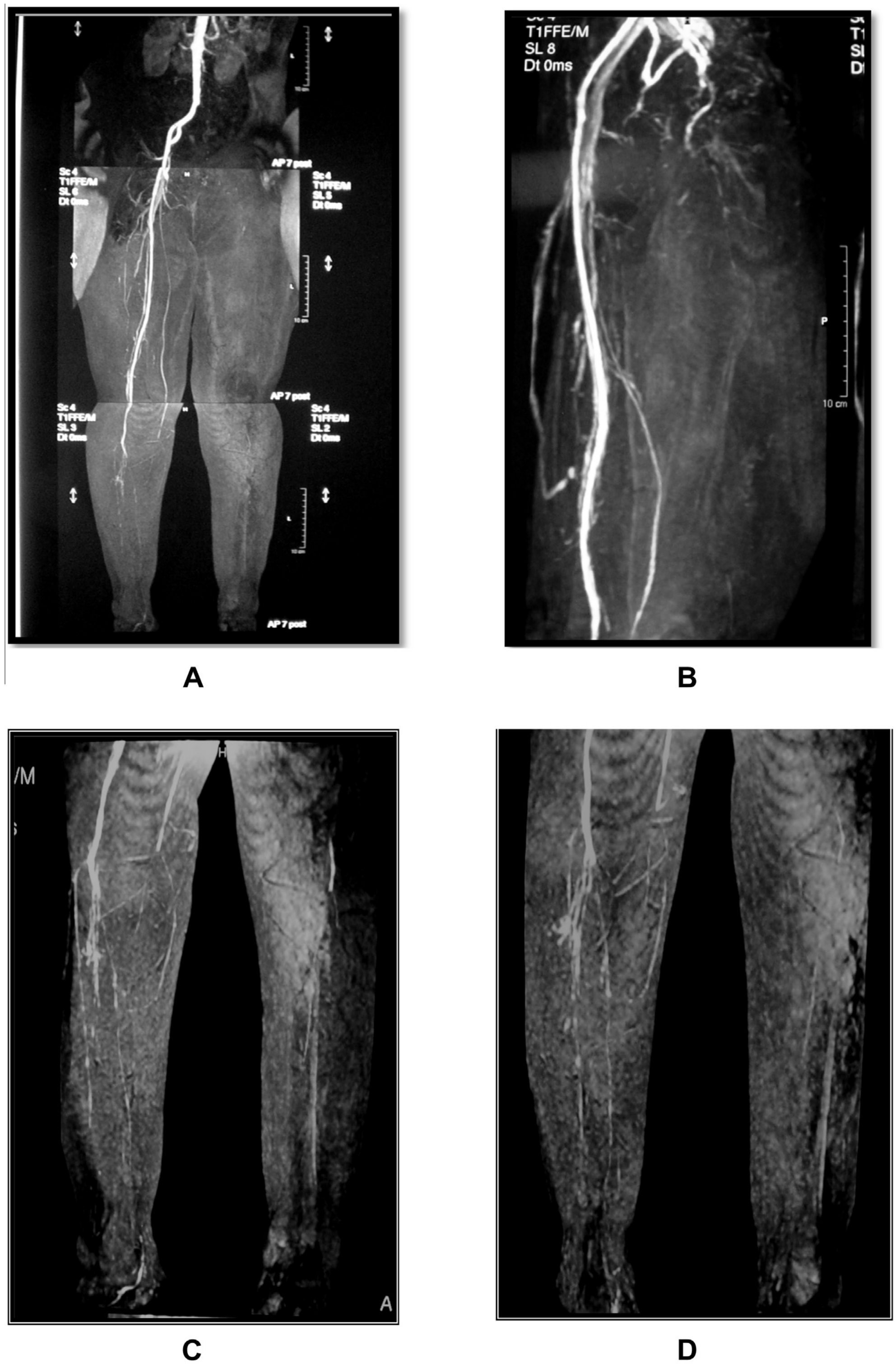

Fig. 3 (A) Angiogram showing patent right posterior tibial artery. (B) MRA showing occluded iliac and femoral arteries. (C & D) MRA showing occluded left infrapopliteal arteries and markedly attenuated right ATA and PTA showing beaded outlines with multiple stenotic segments. (E & F) Angiogram showing occluded left common iliac artery. (G & H) Angiogram showing occluded left superficial femoral artery. (I) Angiogram showing attenuated right posterior tibial artery.

left-to-right (low image-percentage) directions. This is also true for high grade stenoses (stenosis of 75–99%), which sometimes manifested as small complete occlusions. Another explanation for the lower specificity might be the improved measurement accuracy on rotate and enlarged MIP images when the electronic caliper was used, which revealed minor

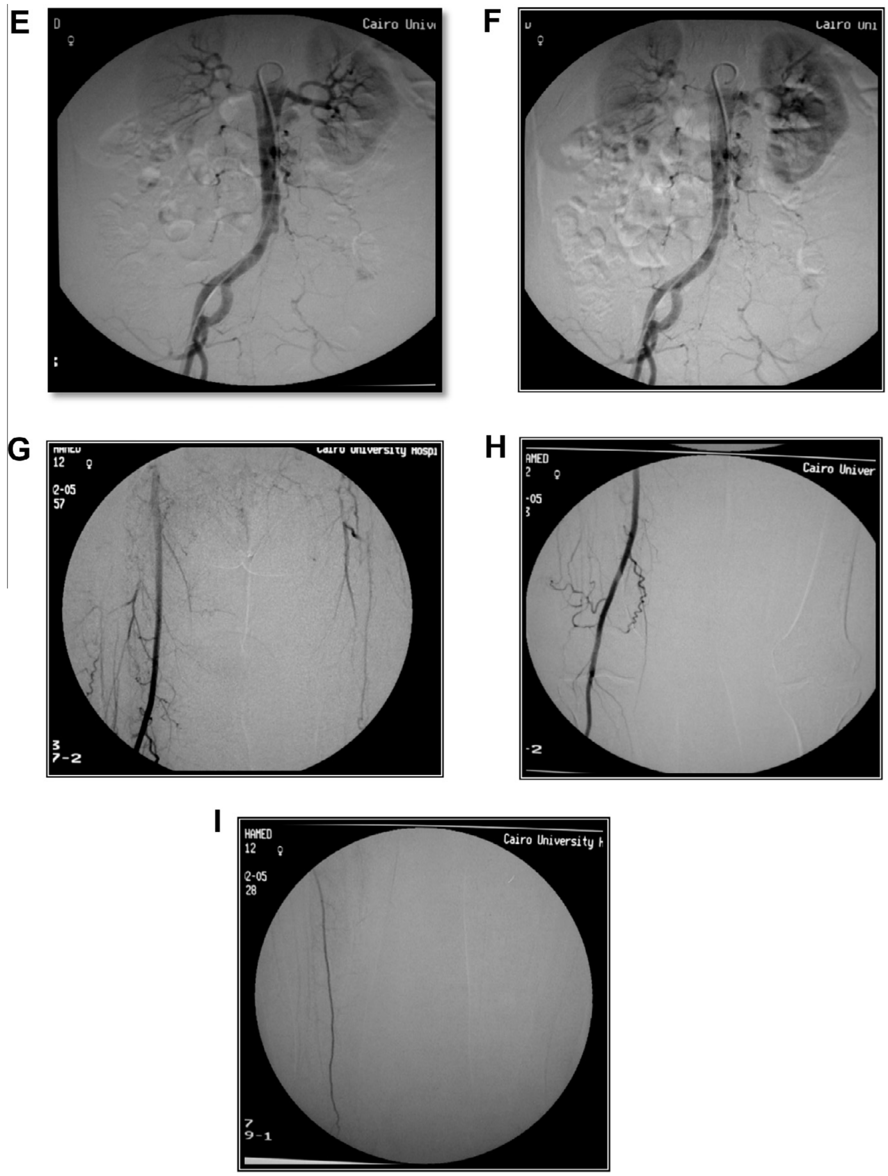

Fig 3. *(continued)*

stenoses that were overlooked on conventional coronal or oblique angiographic views.

The length of stenosis also can be overestimated especially if velocities are high at the stenotic area and the concentration of contrast material is low.

Reid et al. (27) stated that there are several limitations to relying on 3D bolus chase MRA as a standalone procedure. These limitations include unpredictable venous enhancement that can obscure arteries, motion artifacts and the 1.5–2 mm spatial resolution that is inherent to the imaging matrix typically used. These limitations are most pronounced when the infrapopliteal vessels are imaged. Their results showed that diagnostic images were obtained in 100% and 96% of the abdominal-pelvic and thigh stations, respectively but in only 43% of the calf stations.

Ho et al. (28) concluded that, the main problem of the auto-moving table contrast-enhanced 3D MRA was the returned venous contamination. It was particularly problematic for the area below the knee level.

In our study, 21 segments were underestimated by MRA and were reported as occluded by DSA and patent by MRA.

These findings are consistent with those of Meaney et al. (25) who demonstrated 19 of 88 of occluded segments by DSA were patent on MRA. They explained the failure of DSA to detect patent segments by differing flow rates in the two legs due to proximal stenoses. This limitation of DSA can be reduced by using multiple and selective administrations of contrast material, but in some cases, the intravascular concentration of iodinated contrast material is inadequate to demonstrate patent segments. The reason for the MR angiographic demonstration of segments that are thought to be occluded at DSA is uncertain, but it may be related to the potency of gadolinium as a contrast material compared with that of iodinated contrast material, the high sensitivity of the 3D technique for the detection of tissues with contrast material-induced T1 shortening, and the long acquisition time of MR angiography, which allows retrograde filling through the collateral arteries with proximal occlusion.

Similar phenomena were reported by Ho et al. (26) who reported seven of 65 complete occlusions seen on DSA were patent on moving-bed infusion tracking MRA.

Steffens et al. (29) concluded that CE-MRA was superior to DSA in detecting patent vessels not seen in DSA especially in the infrapopliteral region.

A carefully tailored three station moving table MR angiography performed on a scanner equipped with soft gradient technology in association with parallel imaging at the first two locations with bolus detection and optimized K-space filling strategies will deliver high spatial resolution images free from venous contamination in virtually all patients (30).

We believe that this approach will address all of the relevant questions, regardless of symptomatology, and offer the clinician an attractive alternative to invasive testing in all patients who can undergo MR imaging.

Conflict of interest

None declared.

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